Double Slit Interferometry with a Bose-Einstein Condensate

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Several current efforts in the field of dilute Bose-Einstein condensates (BEC) are focusing on the creation of new technological devices, including quantum computers and ultrasensitive interferometers to detect and measure weak forces. Atom wave interferometry provides unprecedented sensitivities to detect rotations, accelerations, and gravity gradients. These sensitivities could eventually be further improved with interferometers based on BEC, which are the highest brilliant coherent sources of matter waves and allow for larger separations between different interferometric paths.

As the initial phase of an extended project to examine a variety of atom-interferometer schemes, we have focused on the simplest example, the double slit experiment [1]. The basic experiment with light by Young dates from the 1800's and was recently voted one of the most beautiful experiments in physics by the readership of *Physics World*. The analogue for BEC was recently realized in an experiment [2] at MIT that employed a double well scheme.

First, a BEC was prepared in a single well and allowed to relax to its ground state corresponding to the single pinhole source of coherent light in the Young experiment. Second, a laser, producing two trapping wells, then split this condensate into well-separated pieces just as the double slit separates the light (see Fig. 1). Finally, the traps were dropped, and the two condensates allowed to propagate ballistically. Their interaction then produced the standard interference pattern.

To examine this scheme in detail, we numerically solved the full 3D time-dependent Gross-Pitaevskii (GP) equation to reproduce all the steps realized in this ideal experiment. We studied the adiabaticity of the splitting process and predicted the interference contrast as a function of the various time scales of the experiment. Finally, we considered the corrections to the GP dynamics arising from quantum fluctuations. Our analysis is quite general, and is relevant, for instance, to the study of the splitting and recombination of a BEC propagating in atom-chip wave guides.

In Fig. 2, we display a comparison between the experiment and the simulations. The simulations reproduce the basic feature of the experiment. The wavy nature of the fringe arises from dephasing complications due to

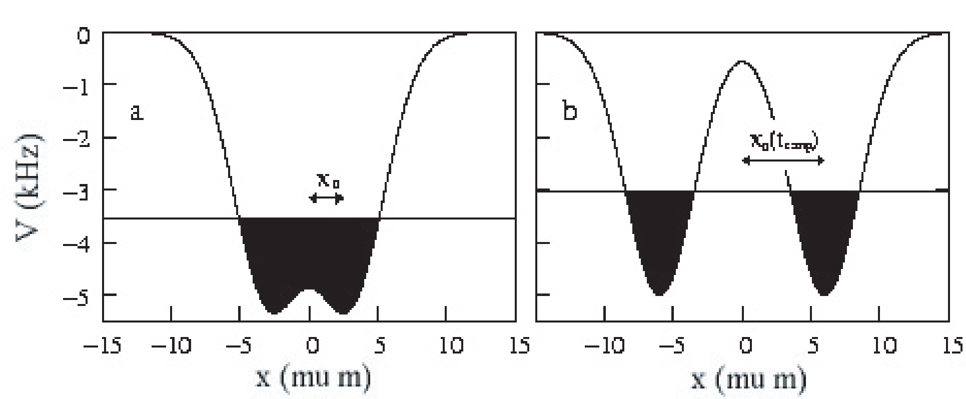

Figure 1— ***Double well potential: a) initial condensate with a distance between the wells of 6 μm; b) displaced wells at the end of ramping process separated by 13 μm. In this configuration, we have two independent condensates.***

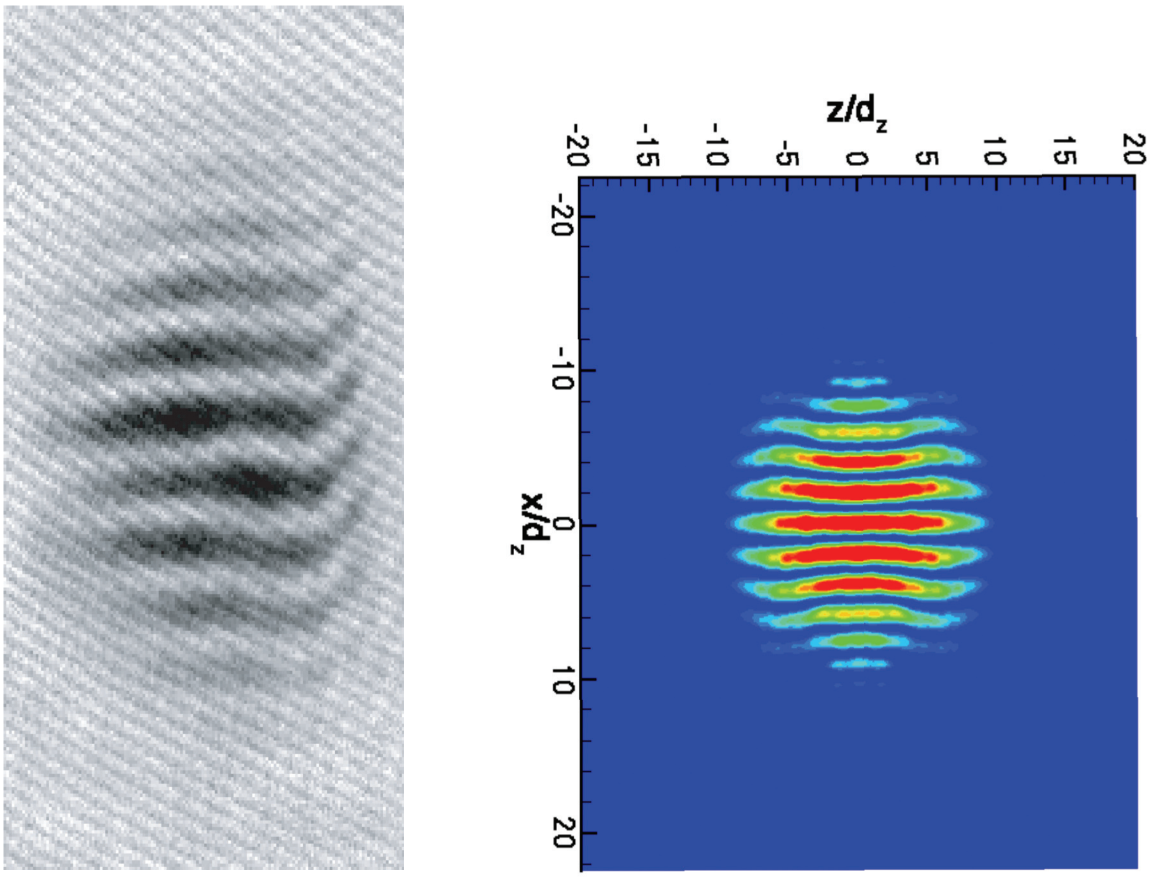

Figure 2—
Comparison of experimental (left) and simulation (right) interference patterns during ballistic propagation of the condensates.

excitations induced by nonadiabatic separation and anharmonic nature of the wells. We have also extended the analysis beyond the GP equation (mean field) and studied dephasing from the nonlinearity of the quantum (many body) dynamics.

[1] L. Collins, L. Pezzé, A Smerzi, G. Berman, and A. Bishop, *Phys. Rev. A* **71** (in press, 2005), cond-mat/040419 (2004).
[2] Y. Shin et al., *Phys. Rev. Lett.*, **92**, 050405 (2004).